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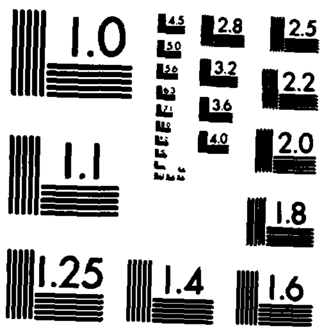

OPY RESOLUTION TEST CHART

AD-A146 679

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PROGRESS REPORT ON CHANNEL CONSTRUCTED TO PROVIDE WELL DEFINED BOUNDARY LAYERS FOR VORTICITY OPTICAL PROBE MEASUREMENTS

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In the period of fall 1983/spring 1984 ~~we have been~~ the authors were predominantly concerned with the design, construction and testing of a new large scale flow system. It appears from preliminary examination that this flow system generates a turbulent boundary layer suitable for wide ranging study of vorticity dynamics. Verification that the flow exhibits normal boundary layer characteristics with both flow visualization and hot-film anemometry is under way.

I. Introduction

The Vorticity Optical Probe (VOP) provides a mesure of local vorticity fluctuations [1,2]. It is based upon the tendency of small spherical particles to rotate with angular velocity, ϕ (omega), as ϕ (omega) = W/2 determined by the local fluid vorticity W. To measure the particle rotation, plane mirrors (15 μm (micron) lead carbonate platelets) imbedded in about 25 μm (micron) Lucite (PMMA) spheres are the vorticity probe particles. Laser light reflected from the rotating particles allows the local vorticity to be deduced. Clearly, the refractive index of the working fluid must be matched to that of the polymethyl methacrolate particles (n=1.49) to eliminate refraction at their spherical surfaces. The choice of working fluid to match the particle refractive index has a direct effect on the flow system construction design and materials selection: ~~we have~~ the authors selected a 60 wt.% aqueous solution of ZnI_2 (zinc iodide) with n=1.49, density ρ=1.7 g/cc and viscosity ν=0.01 cm^2/sec. This fluid is

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moderately corrosive, perhaps comparable with sea water, but it does appear practicable for use in moderate scale flow systems and thus extends the usefulness of the vorticity probe. These along with other physical considerations ~~will be~~ are discussed in part II.

Ideally, the study of boundary layer turbulence would be conducted on a smooth flat plate with uniform flow at infinity, no plate end effects, and negligible disturbance by extended flow structures and background turbulence in the incident flow. To minimize the scale and cost of the tunnel, compromises were required. Nonetheless, it was our goal to simulate the above "free" boundary layer conditions, to the maximum extend that this is possible in a modest scale flow tunnel suited to application of the VOP geometry using the available technical experience, in order to confirm the precision and accuracy of the probe for study of the vorticity dynamics of both transitional and turbulent flow and to carry out precise studies on well defined flows. Our preliminary experiments had established many of the relevant parameter ranges. Both the conventional and novel aspects of our design approach pertaining to the production of this nearly "free" boundary layer will be examined in part III. Many expert researchers provided helpful advice for our design and it is acknowledged below.

II. Materials and Structural Design

The channel is constructed entirely of Plexiglas. Plexiglas is impervious to the corrosive ZnI_2 solution, and because the refractive index is matched to PMMA (Lucite or Plexiglas) there are no interior optical boundaries. It is light and easily machined. The pieces were glued with 1,2-dichloro-ethane. A section-by-section modular design was chosen in order to simplify construction, repair and necessary modifications. Sections are bolted together and sealed with Viton O-rings. A schematic of the system is shown in Fig. 1.

The diffuser and turning vanes are stainless steel. The main recirculation pumps are Flotec model S16 submersible centrifugal pumps constructed of chlorinated polyvinyl chloride (CPVC) with 140 GPM capacity each. The plumbing is PVC except for a section of 4 inch stainless bellows in the return line and thin walled hose on the pump intakes for vibration damping and isolation.

The channel rests on a 15 foot box beam constructed of laminated plywood to prevent significant channel bending or twisting. Such strains due to the weight of the dense ZnI_2 solution (about 500 lbs) could have eventually caused severe cracking. The argon ion laser used in the vorticity experiment is mounted within the box beam to minimize the motion of the laser beam with respect to the channel and the vorticity probe optics. The laser is thus also fully protected from even catastrophic leaks.

Because of the expense and anticipated limit of the lifetime (about six months at $2,500 per fill) of the ZnI_2 solution, we have made great effort to maximize the "quality" of the boundary layer with the minimum total volume of fluid. This compromise has resulted in a volume of less than 150 liters, though the fluid passes through the 4×24 cm entrance of the test section at up to 1000 liters/min (more than 1.5 mps in the free stream).

The probe particles are slightly less dense than the working fluid and would eventually float to free surfaces and the top walls of quiescent fluid. The multipurpose skimmer serves not only to bleed air from the system, but also remixes particles as they are swept in from the low speed region upstream. That particles collect on free surfaces is beneficial in that it affords a manual method of varying their concentration in the flow by simply stirring them up. Baffles have been placed in the dump tank and skimmer buffer tank to prevent air from being entrained at the free surfaces. Some difficulties with air bubbles have been encountered. Figure 2 is a photograph of

the upstream fluid pathway and the entrance to the channel test section.

III. The "Free" Boundary Layer

Proceeding from the return line downstream the following describes the preparation of the flow and the boundary layer.

1. Diffuser and turning vane section. The stainless steel diffuser consists of two concentric cones with right angle vanes intersecting at the axis. The incoming jet is thus dividied into three sections which slow and distribute the flow without separation. The ratio of turning vane arc length to vane separation ranges from 8 on the outside corner to 3 on the inside corner so that turning efficiency is good.
2. Honeycomb and screen section. The honeycomb is made of soda straws packed into a frame and fused by heating in an oven. The 1/8-inch straws with 40:1 aspect ratios will likely prove the most efficient in smoothing the velocity profile per head loss in this flow. The screens that have been selected initially for trial purposes are stainless steel square mesh with successively 16/inch, 30/inch, and 80/inch mesh, separated by less than 5 mesh lengths of the upstream screen. The resulting free stream turbulence intensity has not yet been measured.
3. Contraction. The 5th order contraction is one-dimensional with a 5:1 contraction ratio. The length to width reduction ratio, $\ell/2d$ in Fig. 1, is 2:1 which prevents distortion of the velocity profile and maximizes the radius of curvature on the concave wall. This concave wall presents some well known complications. The criterion for the suppression of Görtler vortices [3] on concave walls is generally

$$R_G = R_\theta \sqrt{\theta/R} < 0.3$$

where θ is the momentum thickness, R_θ is the Reynolds number based on θ, and R is the radius of curvature. Above this value, paired streamwise vortices are likely to form. Since streamwise vorticity is generally considered to be of primary importance in turbulence production in boundary layers, and we measure this quantity directly, it is of course the last thing we want convected into the test section. Estimates of θ on the concave wall give $R_G \approx 3$ which is an order of magnitude above the critical value. Preliminary flow visualization studies seem to indicate that Görtler vortices may be present in the contraction. This problem is countered by the skimmer.

4. Skimmer. A special (optional) feature of the flow system is a boundary layer "skimmer." Figure 3 is a streak line photograph of the (untuned) flow in the skimmer viewed from the top. The skimmer is expected to be superior to ordinary boundary layer suction techniques for eliminating disturbances otherwise convected into the test section, since those disturbances near the wall are totally eliminated from the flow. Immediately upon exiting the contraction a 0.5 cm wide strip around the entire perimeter of the flow is diverted into the skimmer manifold. The skimmer has a separate pump which draws fluid from a closed buffer tank into which the manifold empties. This buffer tank is so called because several inches of air at the top help to damp flow pulsations caused by the pump, which might cause periodic flow fluctuation at the leading edge of the new boundary layer. Figures 4 and 5 show close up cross sections of the skimmer flow. (Flow is left to right.) A plane of laser light illuminates aluminum flakes in water as they flow past. Figure 4 shows the flow improperly tuned (the skimmer is drawing too much fluid relative to the main flow).

Figure 5 shows the correctly tuned condition. Note the bright streak line at the bottom of Fig. 5, perhaps a Görtler vortex or an associated secondary flow, being diverted from the test section. A total of 25% of the flow is drawn off.

5. Test section. The leading edge of the boundary layer (in the skimmer) is a flat edge 10 mils thick serving as both boundary layer origin and trip. There is only a single seam in the test section and care has been taken to match the interior surfaces to within 2 mils. The entire test section is 2.2 meters in length and diverges slightly. At the entrance it is 4×24 cm and 5×25 cm at exit. The turbulent boundary layer growth would result in an increase in centerline free stream velocity, U_0, in a straight test section. The diverging channel is designed to maintain constant U_0.

The Reynolds number based on channel width at top flow speed is 6×10^4 and based on displacement thickness, R_{δ_1}, is 600 at 10 cm from the leading edge (and $\delta_1 \approx 0.04$ cm). The transition to turbulence should begin in this region, and the turbulence is well developed near the end of the test section.

That the aspect ratio is only 6:1 does not present difficulties. The boundary layers on opposite walls have nearly merged only at the very end of the test section, and the effect of end walls is negligible at the center of the span. The flow exits unrestricted into the dump tank.

6. Concluding remarks. The combination of careful upstream preparation of the flow, the novel skimmer system and the diverging channel should result in a reasonably good approximation to the ideal boundary layer. Removing the skimmer system, the wide diverging channel can be replaced by a narrow 2×25 cm straight channel 3 m in length for measurements of vorticity in fully developed steady state turbulent channel flow at speeds up to 3 mps.

With the completion of the boundary layer characterization, we will proceed with the first sytematic study of vorticity dynamics in a turbulent boundary layer at the high level of precision and resolution made possible by the Vorticity Optical Probe.

[1] M. B. Frish and W. W. Webb, J. Fluid Mech. 107, 172 (1981).

[2] R. D. Ferguson and W. W. Webb, "The Vorticity Optical Probe: A Fast Multicomponent Model," Proc. Eighth Biennial Symposium on Turbulence, September 26, 1984, University of Missouri, Rolla, MO.

[3] H. Görtler, Nachr. Ges. Wiss. Gött. Math. Phys. Kl.1, 1-26 (1940) (translated as NACA Tech. Memo 1375).

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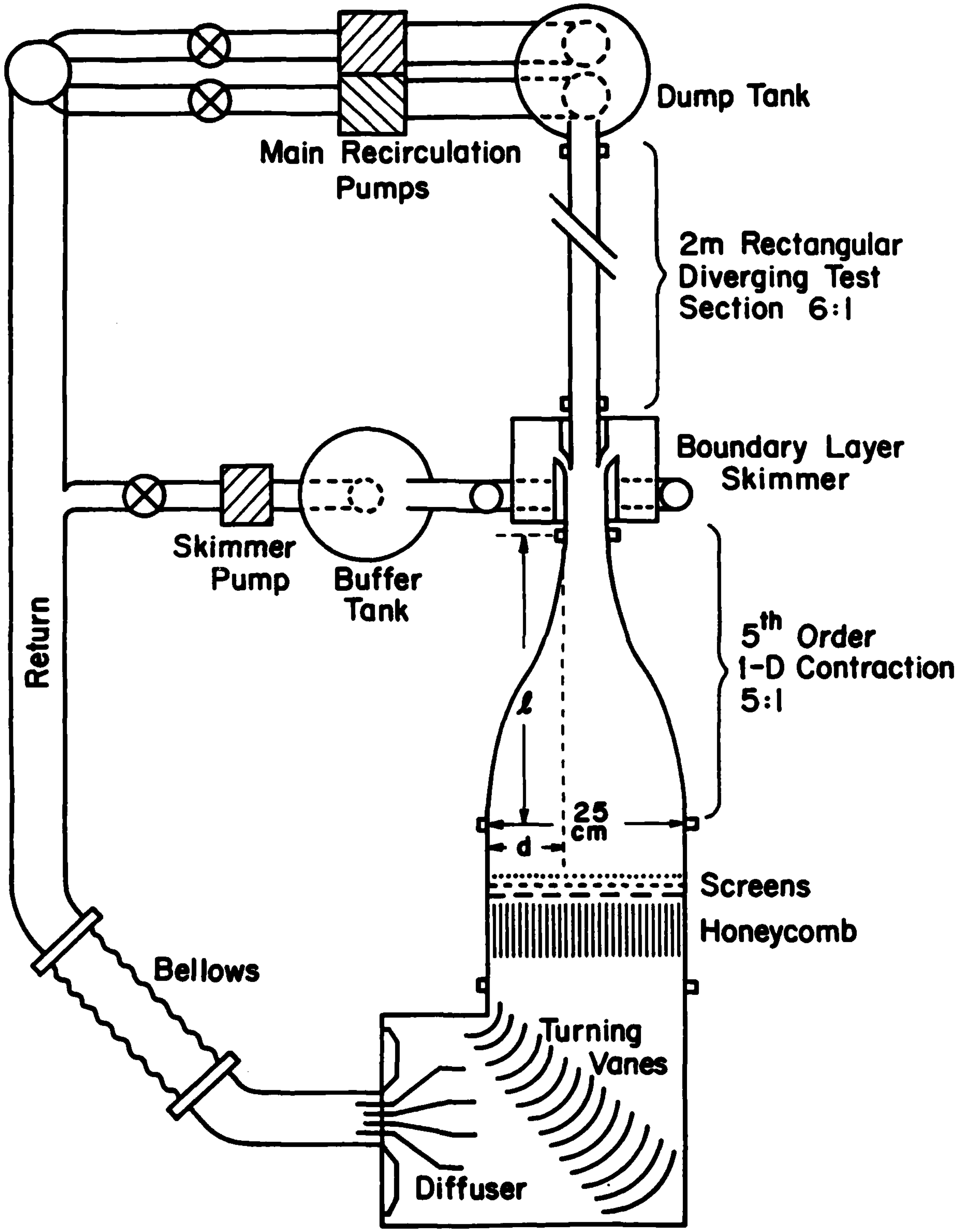
Dump Tank
Main Recirculation
Pumps
2m Rectangular
Diverging Test
Section 6:1
Boundary Layer
Skimmer
Skimmer
Pump
Buffer
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Fig. 1.

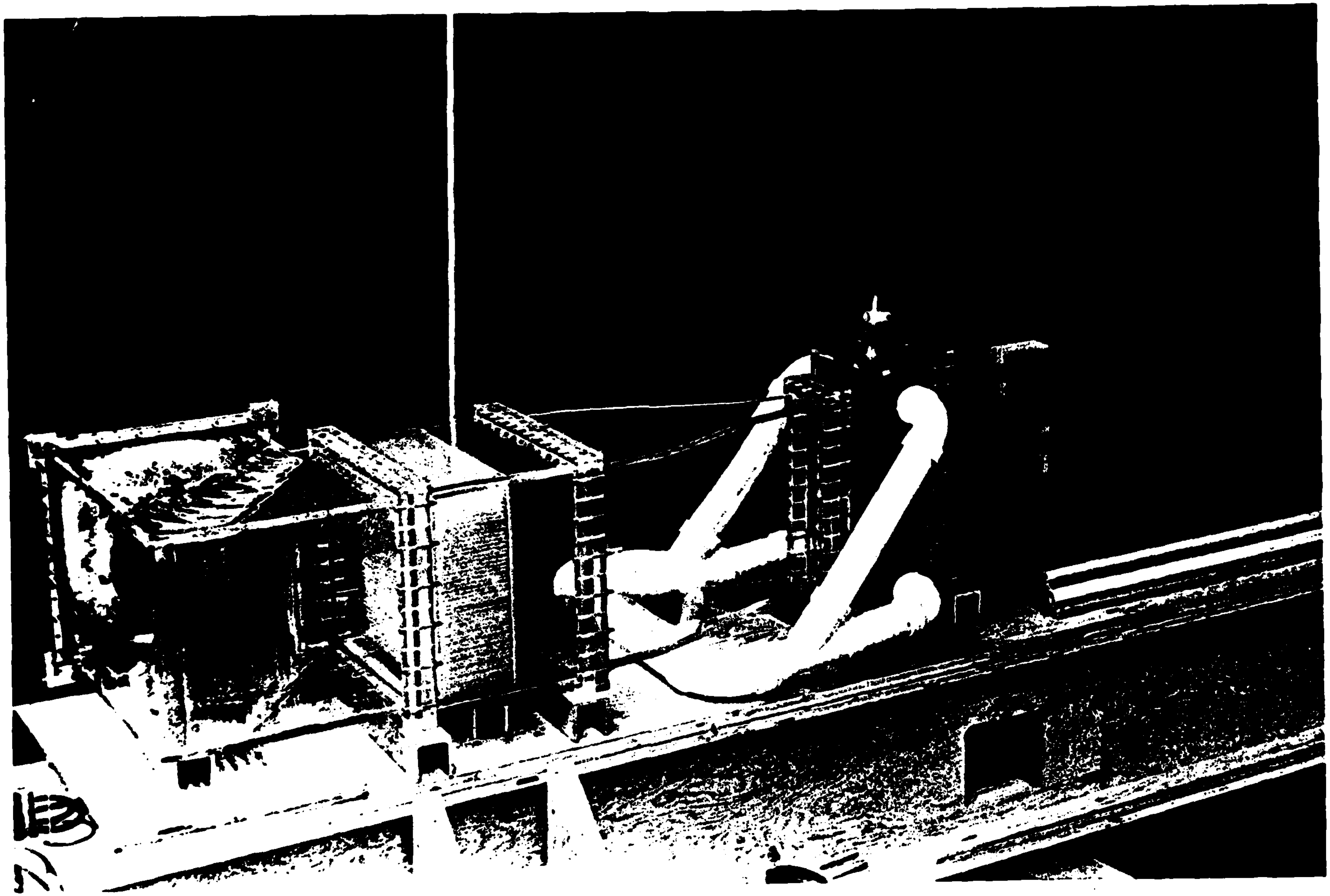

Fig. 2. Upstream sections of the channel.

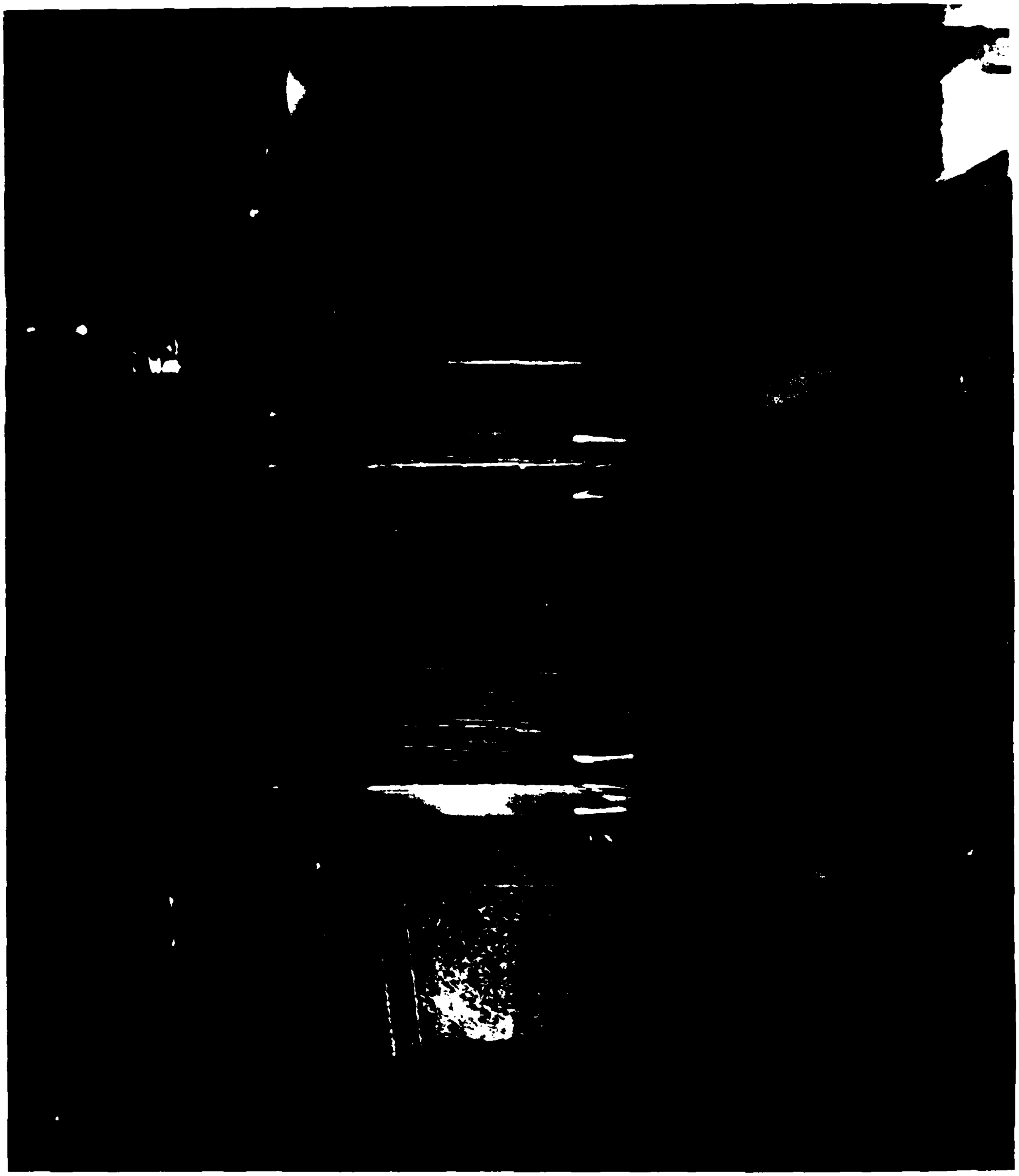

Fig. 3. Skimmer. Top view. Streak lines show that the pumps are not properly throttled. (Flow left to right.)

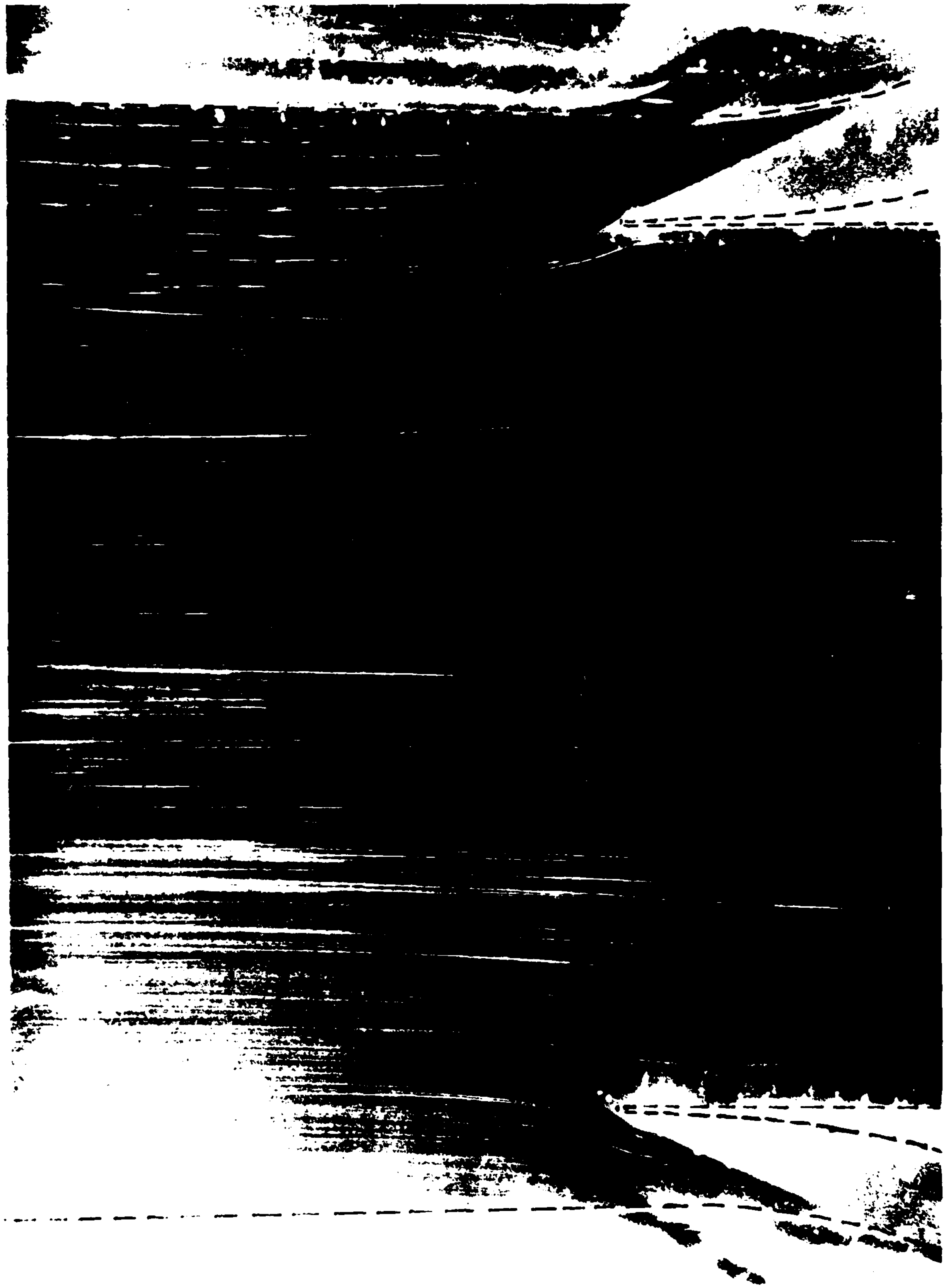

Fig. 4. Skimmer. Top view closeup. Pumps improperly throttled. The skimmer is drawing too much fluid relative to the main flow. The actual cross section of the skimmer in the plane of the laser light is obscured in the photograph so it has been sketched in.

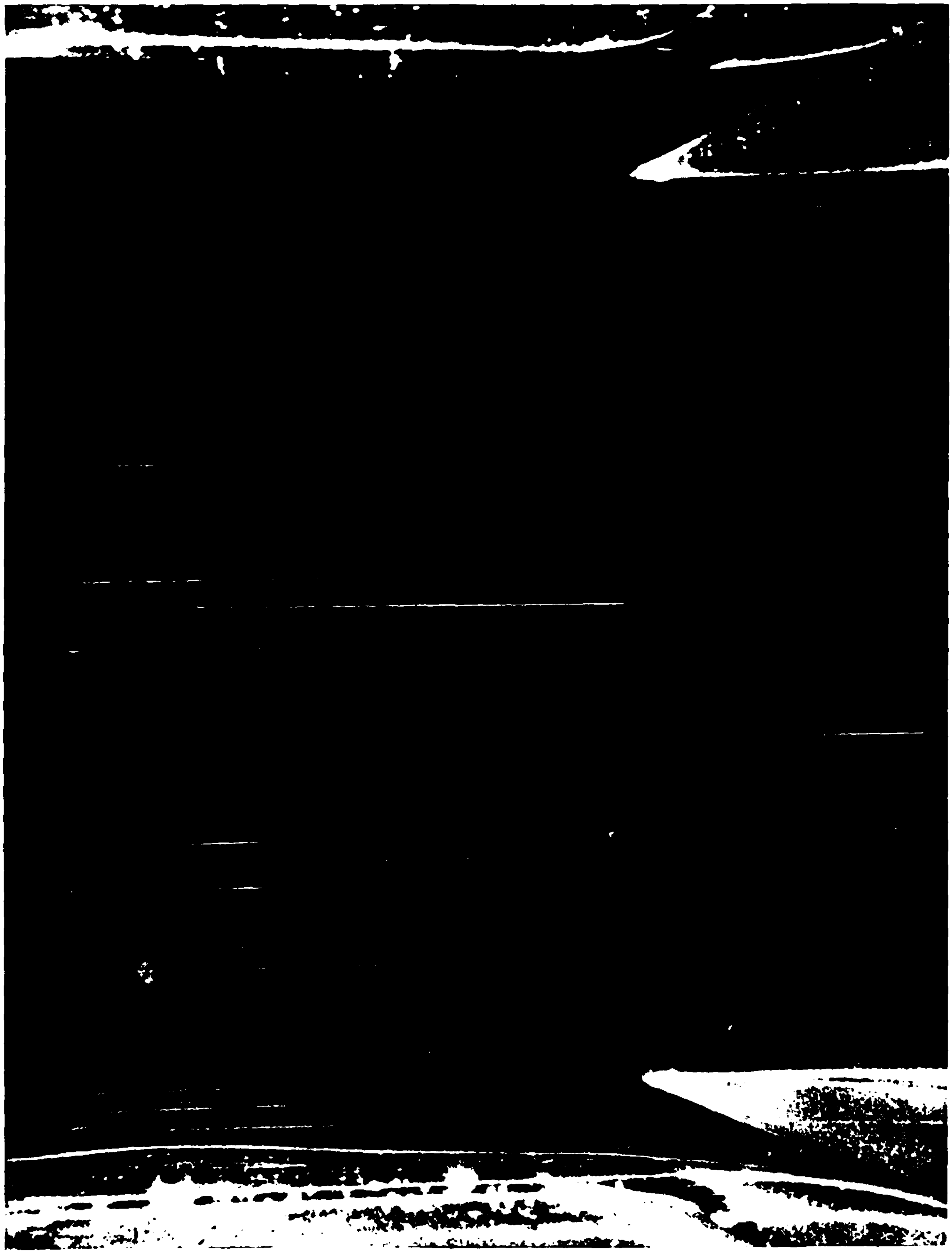

Fig. 5. Skimmer. Properly throtted. The passage of some large scale disturbance is visible at bottom.